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Spacecraft Optical Contamination Environment

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In the framework of this program the Lockheed Palo Alto Research Laboratories is performing a joint experiment with AFGL to make observations of shuttle induced emission effects such as shuttle glow and thruster induced effects. In addition, observations will be made of natural background phenomena such as the aurora and airglow. At very high latitude when the shuttle transits the auroral regions we shall attempt to observe the direct effects of precipitation and precipitation induced discharges. In this program the Air Force will be flying Lockheed instrumentation as secondary payload on the shuttle and the payload or mission specialists will make observations through the orbiter windows with the equipment. The hardware is essentially a re-flight of the Auroral Photography Experiment (APE) which was flown on mission 41-G augmented with the spectrometer and Fabry-Perot. The APE experiment will be reflown again in the near future with the expanded configuration, Configuration B which includes the spectrometer and the Fabry-Perot. Keywords

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The Auroral Photography Experiment (APE) Configuration B

ABSTRACT

In the framework of this program the Lockheed Palo Alto Research Laboratories is performing a joint experiment with AFGL to make observations of shuttle induced emission effects such as shuttle glow and thruster induced effects. In addition observations will be made of natural background phenomena such as the aurora and airglow. At very high latitude when the shuttle transits the auroral regions we shall attempt to observe the direct effects of precipitation and precipitation induced discharges. In this program the Air Force will be flying Lockheed instrumentation as secondary payload on the shuttle and the payload or mission specialists will make observations through the orbiter windows with the equipment. The hardware is essentially a re-flight of the Auroral Photography Experiment (APE) which was flown on mission 41-G augmented with the spectrometer and Fabry-Perot. The APE experiment will be reflown again in the near future with the expanded configuration, Configuration B which includes the spectrometer and the Fabry-Perot.

1.0 INTRODUCTION

Lockheed Palo Alto Research Laboratories is performing in collaboration with the Air Force Geophysics Laboratory an experiment to observe the aurora, airglow, shuttle induced emission effects. Among these effects observations will be made of the shuttle surface discharges during conditions of auroral bombardment, quiescent shuttle glow and thruster induced effects. The Lockheed tasks associated with this program are the providing of the experiment hardware and assisting the Air Force in the flight operational requirements definitions, in flight operations and data analysis. In addition there is an active parallel data analysis effort of the data taken on the prior APE experiment on the 41-G mission. The APE experiment was reflown in 1988 on a DoD mission in hardware configuration A which includes only the filter system. Unfortunately the daylight conditions were unfavorable for data taking. The experiment is being prepared for re-flight with hardware configuration B which includes the spectrometer and the Fabry-Perot interferometer.

2.0 SCIENTIFIC OBJECTIVES

The APE experiments were envisaged to make auroral observation from the shuttle to investigate atmospheric natural background light emissions. In recent years some advance was made towards the understanding of artificially induced emissions. The presence of the spacecraft body induced emissions were discovered. This emission in the visible spectral range was termed as shuttle glow. Through a sequence of experiments we were able to characterize shuttle glow and gain some understanding of the physical processes generating the glow. However there is still some work necessary to verify some aspects of the theory. Another source of strong background light is provided by the attitude control jet thrusters. So far there is very little experimental data concerning the spectral character of this emission. Over the years therefore the priorities of the Auroral Photography Experiment (APE) have shifted from the observation of purely natural phenomena of auroral and airglow towards the investigation of shuttle glow and thruster emissions.

2.1 Spacecraft Induced Glow

Glows associated with space experiments are not new. A rocket experiment flown into the mesosphere and lower thermosphere in 1956 (Heppner and Meredith, 1958) cited optical backgrounds in visible photometers near the 100 km altitude region. These early experiments noted background ratios in the background signal of photometer channels suggesting a continuum type emission. Nitrogen Dioxide emission was reported as a likely explanation of the phenomena. It wasn't clear in this early rocket data whether gas phase reactions were taking place without gassing contaminants or whether there was a surface reaction involved.

The AE-C and -E satellites were equipped with a Visual Airglow Experiment (VAE) which observed atomic and molecular features in the earth's airglow layer. Backgrounds in the filter photometer channels of AE-C were found to have a variability with ram angle below 170 km according to Torr et al.,(1977). A thorough analysis of the data from AE-C and -E was reported by Yee and Abreu (1982, 1983) over the altitude range of 140 to 300 km. The data displayed a detectable level of luminosity in the near UV channels of the instrument (3371 Angstroms), with increasing luminosity towards the red wavelengths (7320 Angstroms). The background in all filter channels, when plotted, described a bright ram source, increasing in brightness toward the red wavelengths. The analysis indicated that the glow extended well away from the spacecraft suggesting the probability that the emitter is a metastable. The Yee and Abreu (1982, 1983) analysis reported a strong correlation between the ram emission intensity and altitude. The emission intensity closely followed the atomic oxygen scale height above 160 km altitude. This discovery of the glow relationship to the oxygen flux was an important key to establishing and understanding of the physical process leading to the glow.

Glow observations have been reported by a number of investigators from Shuttle missions STS 3, 4, 5, 8, 9, 41D, 41G, 51D and 61C (Refs: Banks et al., 1983; Mende et al., 1983: Mende, 1983; Mende, 1984; Mende et al., 1984 a, b, & c; Torr and Torr, 1984; Torr, 1985; Swenson et al., 1985 a & b; Mende and Swenson, 1985; Kendall et al., 1985 a & b; Mende et al., 1986; Swenson et al., 1986 a & b; Kendall et al., 1986; Tennyson et al., 1986). Banks et al. (1983) reported glow from orbiter television and still camera pictures around aft spacecraft surfaces while documenting glows associated with an electron accelerator experiment on STS 3. Ram glows associated with STS 5, 8, and 9, have been documented (Mende 1983, Mende et al. 1983, 1984a, 1984b) using an intensified camera. On the later missions (STS-8 and -9), objective grating imagery of spacecraft glow from the vertical stabilizer depicted a red structureless glow (Mende et al., 1984 b & c). The spectral resolution was on the order of 150 angstroms. On the STS-8 mission it was observed that glows from surface samples including aluminum, kapton, and Z306 (a polyurethane black paint typically used in low light level detection instrument baffles) were not equally bright. The surface characteristic and/or the material make up clearly was shown to effect the glow brightness.

High spectral resolution measurements of the ISO spectrometer on STS-9 (Spacelab 1) show the presence of N_2 1PG bands (Torr and Torr, 1984 and Torr,1985). There are also a number of other observed emission features which may be part of the natural auroral and airglow background environment and, therefore, may not be be part of the shuttle glow.

UV glows were reported in the 2800 and 3371 Angstrom channels of AE spacecraft (Yee and Abreu; 1982, 1983). The UV glows were considerably weaker than those in the visible on that spacecraft. It has been postulated that the UV glows from NO might be likely on ram surfaces (Barrett and Kofskv, 1985; Green et al., 1985 a & b; Kofsky and Barrett, 1985; Swenson et al., 1985 b and 1986 b). Tennyson et al. (1986) reported no component of UV ram glow in their attempts on STS-61C. The 61C instrument was not looking at a surface and was a spectrometer with a small aperture. If UV glows are present from NO, they would be expected to be a very thin layer close to the surface. The Berkeley EUV experiments on STS-9 had fogged film and one of the contributing possibilities has been ram glow. S3-4 satellite UV instrumentation (Huffman, 1980) have found N_2 LBH emission to originate near the spacecraft (Conway et al., 1987). Torr et al. (1985 b) have observed shuttle induced emission in N_2 LBH also. Kofsky (1988) and Swenson and Meyerott (1988) have proposed recombination of N on the surface as being responsible. Swenson and Meyerott (1988) have found that a large source of N is likely in the plow cloud of low altitude spacecraft due to atom exchange with the ramming atmosphere. This mechanism predicts a source flux and altitude distribution that supports the observations.

Chakrabarti and Sassen (1985) have reported anomalies in the FUV from data acquired on STP78-1 satellite. Interpretation of Lyman alpha (1215 A) intensity modulation with ram angle suggest several hundred Rayleighs of unexplained emission. Conclusive deduction of the source was not clear in the report. A ram modulation of 400 Raleighs in the LBH bands was also reported. These observations were made at 600 km altitude.

Ground based measurements of the infrared shuttle glow have been reported by Witteborn (1985). Also, the Spacelab 2 IRT experiment reported backgrounds which were much in excess of what was expected from natural causes. How much, if any, of the IR glow is related to the process producing the visible glow is not clear. The IR glows are extended well away from the spacecraft and are speculated to result from gas phase reactions of off gassing constituents including charge exchange with the ambient ionosphere.

In regards to the visible shuttle glow, a spectrum was reported from STS 41D with 34 Angstroms resolution by Mende et al., (1984 b) and Swenson et al., (1985 b). These data show the shuttle ram glow to be an emission continuum within the instrument resolution. This spectrum was convincing evidence to suggest that OH and N_2 1PG are not the emission species on STS.

The current evidence strongly suggests the visible glow associated with the ramming atmosphere is a result of NO_2 in recombination (Swenson et al.,1985 b). The natural atmosphere is reacting with the 8 km/sec vehicle to produce the phenomena. According to this picture NO is produced by the spacecraft sweeping out atmospheric N and O. Some of the NO which forms, remains adsorbed by the surface. Wall catalytic formation of NO is well known to be efficient in laboratory experiments (Reeves et al., 1960). NO reacts very quickly in 3-body recombination with O to form NO_2. The surface monolayer of NO, then, is exposed to atmospheric O on ram spacecraft surfaces. Since NO_2 is formed by ramming O, the 5 eV O also contains enough energy to unbond the formed NO_2 from the surface. NO_2 having a complex quasi-continuous spectrum, the lack of distinct spectral lines in the glow spectrum is explained. Figure 1 is a schematic describing the postulated sequence of chemical events occurring, leading to the emission process. The bottom portion of the diagram shows the ramming O interacting with surface-sticking NO to form excited NO_2. The excited NO_2 which exits the surface, gives the red glow.

The glow spectrum from 3-body gas phase recombination of laboratory experiments (Paulsen et al., 1970) is blue shifted from the shuttle observations but very similar in shape. The most critical aspect of the NO_2 theory is the lifetime considerations. Yee and Dalgarno (1983) analyzed shuttle data to deduce an average molecular travel of 20 cm (confirmed by Swenson et al., 1986 a). The 70 μsec lifetime of Schwartz and Johnston (1969) or 40 μsec of Bylicki et al., (1984) suggest the NO_2 must be exiting the surface with 2-4 eV translational energy to account for the observed thickness of the glow. There is sufficient energy in the ramming O to account for the rebound energy. It is, however, unprecedented in laboratory experiments to have such an `elastic' process in the surface recombination.

The best evidence for NO formation and sticking on orbiting surfaces is reported by the mass spectrometer investigations and what has been observed in the way of NO, and NO_2. Engebretson and Mauersberger (1979) described in detail, the response of NO with respect to thermal and orbital parameters for their instrument on AE-C satellite. It has been known since mass spectrometers first flew, that most of the atmospheric NI entering the mass spectrometer orifice, converts to NO with wall collisions and in fact, a large percentage of the NI signal is deduced from the NO (mass 30) signal in the instruments (see Engebretson and Mauersberger, 1979 and the references cited therein). It has been well established in laboratory experiments that the NI and O wall reaction form gas phase NO. Engebretson and Mauersberger (1979) then reported a most interesting phenomenon. They reported that NO was absorbed on the spectrometer walls (with efficiencies higher at low wall temperatures). The top part of the chemistry shown in Figure 1 reflects what has been observed in the mass spectrometer orifice. They observed the gas phase NO, and from temperature and altitude geometry, they deduced that a significant amount of NO was sticking to the wall. More recently, Engebretson (1986) and Engebretson and Hedin (1986) have presented detailed analysis of specific orbits of DE satellite wherein the wall effect in the mass spectrometer orifice is pronounced with wall temperature modulation. Von Zahn and Murad (1986) have found from mass spectrometer measurements

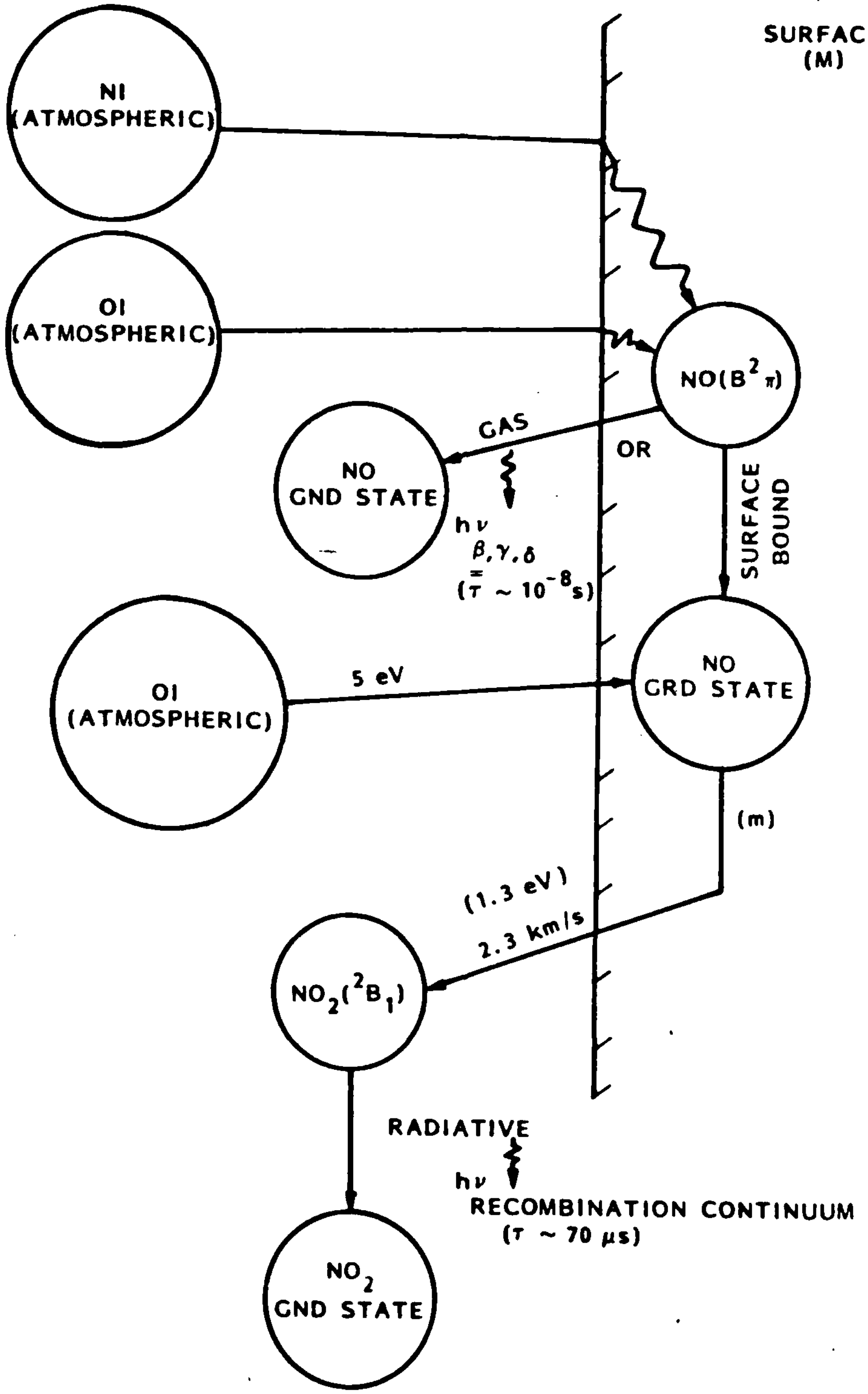


Figure 1. Schematic representation of the atomic N and O chemistry leading to the formation of NO_2 in an excited state.

from a shuttle mission (STS-41B) that the exit flux of NO_2 is more than sufficient to account for the observed glow intensities reported on earlier missions.

The analysis of intensity of shuttle glow has been performed on several missions. The measurements from STS-41G at low altitude added a confusing data point to the existing data base. The intensity on this mission was much less than it had been measured on previous missions (Kendall et al., 1986). After further investigation, it was found that the surface temperature for this particular observation was much warmer than earlier observations. A study of all the previous intensity measurements along with a thermal modeling study of the tile temperature for the associated glow measurements was undertaken. When the temperature history of the ram tile surface was modeled for three measurements of glow intensity from three different missions, it was found that the results of this study (Swenson et al., 1986 b) were consistent with the NO theory and in fact provided a measure of the surface bond energy the NO had with the surface (~.14 eV). The study further suggested that the lesser intense glow seen on the AE spacecraft (which had surface temperatures much warmer than the shuttle tile during observations) was also consistent with these findings.

In the earlier section, we discussed the results showing that the apparent glow intensity above surface samples varied in intensity over respective samples. A thermal model was performed for these material samples which were mounted on the insulating `beta' cloth on the RMS. The predicted glow intensity associated with the temperature of each material sample was found to be in reasonable agreement with the measured intensity associated with each sample. The emissivity associated with each material was largely responsible for the different cooling rate associated with each sample. The early conjectures, that material traits such as cleanliness or a surface chemistry associated with one and not the other, we feel were incorrect and that `temperature' can also explain what we saw.

In the near infrared we would expect to see some emission intensities due to the near IR portion of the NO_2 continuum. It was shown in laboratory experiments that the shape of the NO_2 continuum strongly depends upon the type of reaction which produces the NO_2. Since the shuttle glow production is some form of surface catalytic reaction it is not surprising that the shuttle glow continuum is somewhat red shifted from the spectrum of the laboratory produced gas phase reaction (Swenson et al., 1985 b).

Shimazaki and Mizushima (1985) predict a mechanism for shuttle glow production in which the NO molecules get vibrationally excited through collision with shuttle surfaces. Green et al., 1985 makes a case for NO vibrational overtone transitions having a substantial contribution in the visible region. If this were correct then the corresponding IR transitions at 2 and 3 microns would be several order of magnitude greater than the visible component. Green, et al., suggest that the glow intensity might be comparable to earthshine in the infrared and therefore may be several mega Rayleighs of emission.

Torr (1987) has reported that at lower altitudes (250 km and below) a spacecraft will generate a dense layer of gas due to the "snow plow" effect. Accordingly, in the spacecraft frame of reference, the fast streaming ambient atmospheric molecules have a large probability of collision with the particles which are caught in this region.

Because the masses are generally similar, there will be a very efficient redistribution of the ram energy of the incoming molecules. This would result in a high kinetic temperature in this dense region. Although no particular mechanism was proposed, it was suggested (Torr, 1987) that this region would produce intense gas phase molecular emissions in the IR region.

2.2 Thruster Induced Glow

It is by now well documented that when the thrusters on the shuttle are fired, there is a large enhancement of the surface glow, in addition to the bright gas phase glow region that is apparently not associated with surface processes. The latter is quite transient and must be very bright, whereas the surface glow persists for times on the order of 30 seconds before fading to the normal background glow level. The investigation of this gas phase glow has gained importance lately because this provides an opportunity to study the interaction of unburned rocket fuel with the ambient atomic oxygen atmosphere.

There are several examples of shuttle closed circuit cameras which show thruster firings. Strong glow is present over the entire frame indicating that the luminous reaction is occurring in the gas phase. Unfortunately currently there is no spectral measurement concerning this gas phase glow.

In addition to this spontaneous light emission it was also observed that there is also a marked enhancement of the spacecraft ram glow after thruster firings. The time development of the thruster firings can be best studied by means of the orbiter closed circuit TV cameras. A thruster firing event documented by the orbiter TV cameras on video tape are included in Figure 2. To aid in the timing of the event a time counter which ran in seconds and one hundredth seconds was superimposed on the frames. The status of this time counter provided a unique identification of the TV frame. The first image at time is a background frame at :53:32. The second and third images show the thrusters while in operation. The following frames show the decay of the glow on the engine pods which persists well after the thrusters had been shut off. The TV sequence (Figure 2) was taken on mission STS-8 at an altitude of 220 km.

Figure 3 shows the thruster induced glow intensity as a function of time. This was obtained by integrating the video signal from all pixels inside of a rectangular area which includes the glow on the port side engine pods This integrated signal was plotted by a chart recorder. Note that the video signal may include a number of relatively unknown parameters such as the signal non-linearities and the time response characteristics of the television system. Nevertheless the effects of these parameters on our conclusions are believed to be negligible. Two observations were plotted on Figure 3. The top one is from the low altitude portion of STS-8 at 220km altitude and the bottom is from STS-3 at 240 km altitude. The decay is considerably longer for the low altitude case.

To investigate the glow production efficiency of the various thrusters an experiment was performed on the STS-8 mission. In this experiment the camera was opened for 2 seconds. During the exposure a selected thruster was fired for a minimum single impulse by manual operation of another crew member. There are 6 vernier thrusters on the orbiter (Figure 4) some of them can be operated singly while others are usually operated in pairs. Four different combination of thruster firings were performed and the results photographed. A two second duration background exposure was also taken in between each thruster firing to assure us that all thruster effects disappeared prior to the next firing. The results are shown on Figure 5 in the form of a collage of the photographic images. The top left picture represents the background image. Since the camera was in the objective grating configuration and the orbiter attitude was such that the velocity vector is from the direction of the starboard wing. Note that the only thruster which has a noticeable effect on the picture background is the downward firing tail thrusters. The following explanation can be provided. The downward tail thruster is directed towards the wing. The gases emitted by the other thrusters leave the vicinity of the orbiter very quickly, however the downward tail thrusters throw their output on the wing where the gases thermalize and will take up the velocity of the spacecraft. This luminous cloud will travel with the spacecraft.

The thruster fuel is monomethylhydrazine which combines with nitrogen tetroxide and the principal neutral products in the atomic O environment, according to Murphy et al. (1983), are H_2O, N_2, CO_2, CO, and H_2, with minor amounts of NO_2 (or monomethylhydrazine, since they each have a molecular weight of 46) and O_2. The neutral densities are typically 7-8 orders of magnitude higher than the charged particle densities. It has also been claimed that there may be substantial amounts of unburned fuel at the beginning and end of a thruster firing.

In the framework of the APE experiment we could obtain a spectrum of the thruster induced glow and could determine whether the spectra is similar to the shuttle glow spectrum. We expect that the gas phase emission directly above the nozzles would be quite a different spectrum. It is known from color photos that this emission has a bluish color. One would probably see the O_2 Hertzberg bands in the blue violet region.

THRUSTER FIRING DECAY

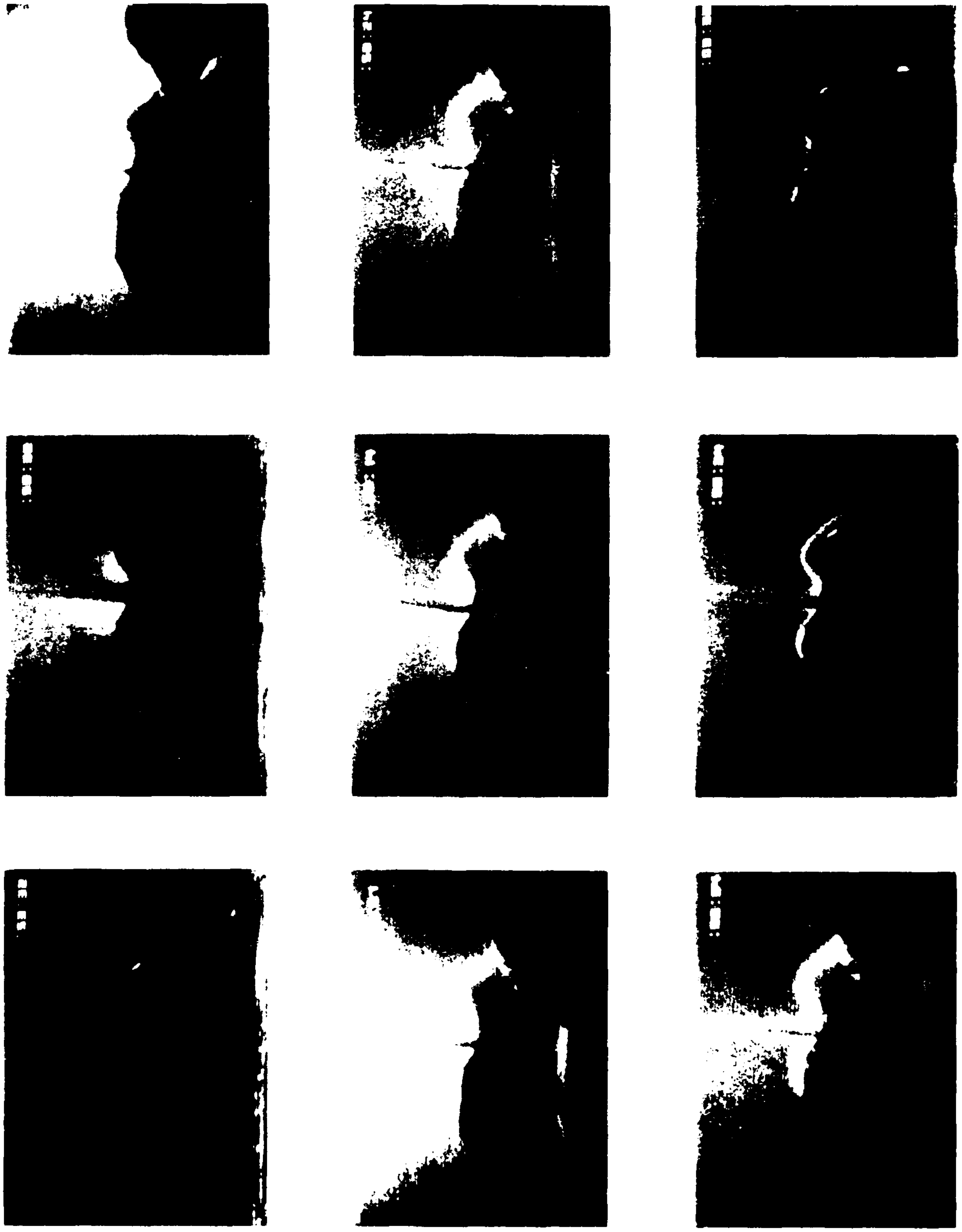


Figure 2. Collage of television monitor photographs of the thruster firing as recorded by the orbiter bulkhead closed circuit television cameras. Time counter in seconds and hundredth of seconds. Note that glow on engine pods is enhanced after jet firing.

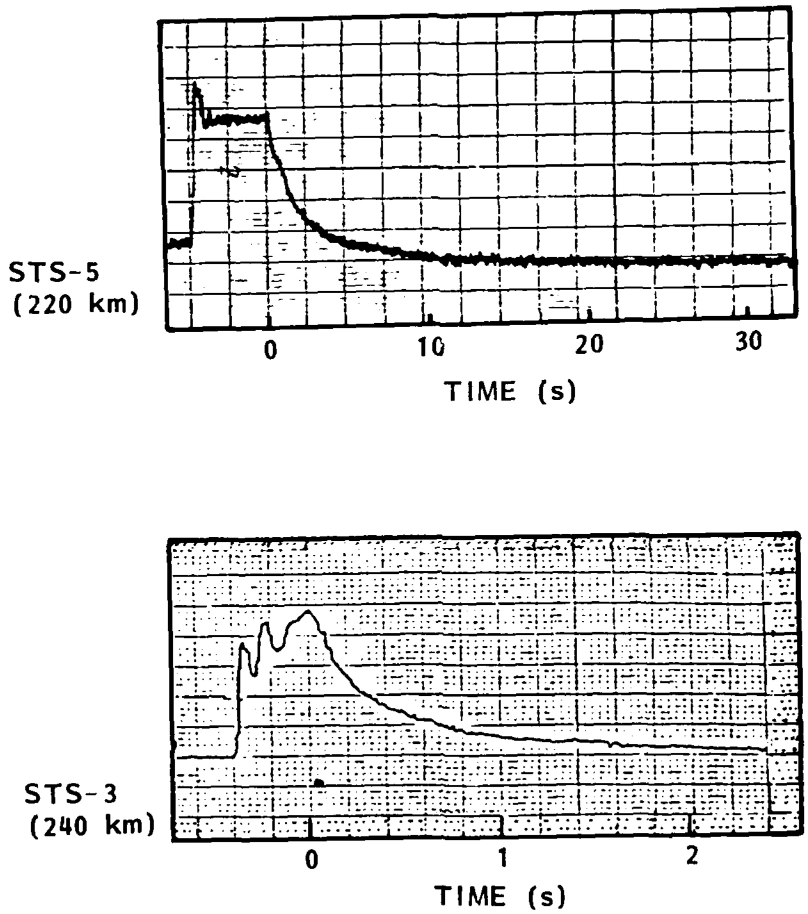


Figure 3. The function of the thruster glow intensity on the engine pods as a function of time after a thruster firing. The data was taken with the orbiter bulkhead video cameras. Intensity is in arbitary units.

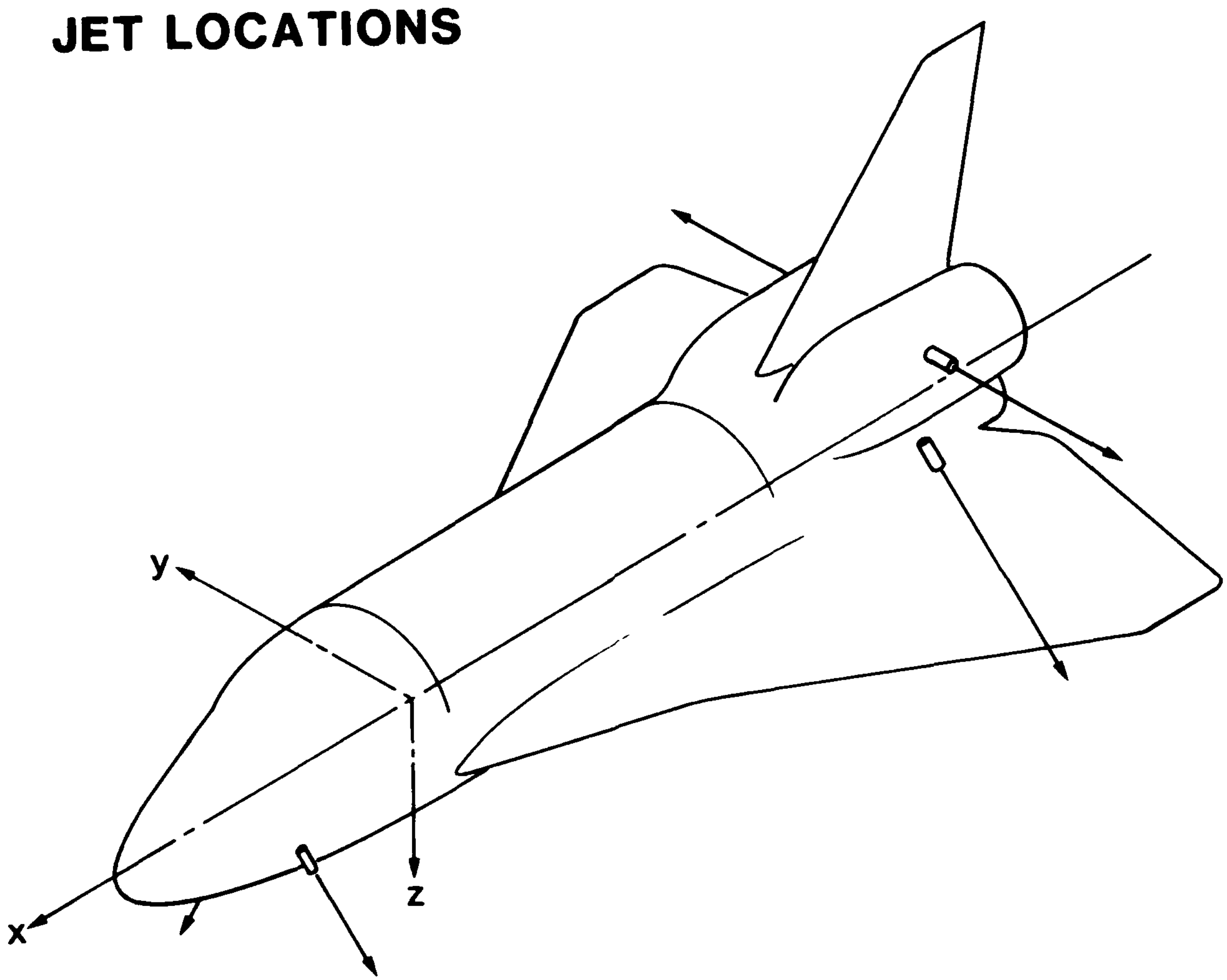
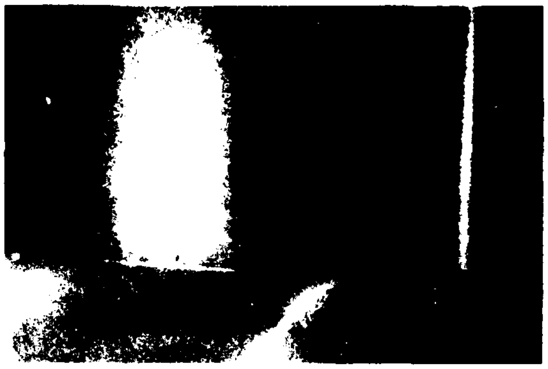


Figure 4. The position of the vernier thrusters on the shuttle orbiter.

THRUSTER FIRINGS

BACKGROUND



FORWARD JETS

TAIL YAW JET 1

TAIL YAW JET 2

TAIL DOWNWARD JETS

Figure 5. The effect of firing thrusters during the exposures. Top left no thrusters fired.

2.3 Natural Background Measurements

Airglow. In addition to the spacecraft induced optical contamination there are a number of other intense background components in the visible and near IR such as airglow emission due to the molecular O_2 and OH. The flight experiment would provide an opportunity to obtain data about the intensity and altitude variations of these bands. Swenson et al., 1988 have used this technique and obtained better than 1 km altitude resolution of the airglow layers. In this work Swenson et al., 1988 used our Spacelab 1 (STS-9) instrument TV video data (Mende et al., 1984 d, 1985), (Sandie et al., 1983) of the visible and UV limb airglow layers. With appropriate star images in the field of view and accurate knowledge of the spacecraft position (position only, not attitude) we can measure the airglow layer altitude with an accuracy better than 1 km. Substantial variation in airglow layer attitudes have been found and there is a possible association with the local lower atmospheric generated gravity waves. Thus, a whole set of limb height measurement could be obtained by making observations in the limb view direction with our instrument complement.

In addition to measuring the intensity profile along the limb there is another important atmospheric parameter which is accessible to remote sensing measurement. This parameter is the temperature of the atmosphere. This can be measured by remote sensing techniques using the rotational lines of the airglow emission. Using the STS-41G data Mende et al (1988) obtained the airglow rotational temperatures of the O_2 (0,0) and the OH bands. The STS 41 G data provided only a very few usable exposures. It is proposed that on the upcoming APE missions we should take a series of temperature measurements to validate the method and to obtain temperature vs. altitude profiles. The rotational line temperature measurement is performed using the camera in the Fabry-Perot configuration.

Aurora. At higher latitudes we can make limb measurements of the auroras. On the limb it is possible to make altitude profile measurements. On 41-G such measurements were performed using the spectrometer. The spectrometer slit was aligned in the vertical direction and limb spectra was obtained. In this manner the auroral lines in the image are an actual height profile of the emission feature. Both the particle energy deposited and the atmospheric composition varies with altitude. The different emissions profiles will provide a number relationships between the spectrum of the energetic particles causing the aurora and the atmospheric composition. This data should help resolving the many discrepancies which still exists in the understanding of the mechanisms of auroral emission.

2.4 Shuttle Electron Discharges

During auroral displays the shuttle in high latitude orbits directly encounters the auroral bombardment. Auroral electrons are several keV in energy. Insulators on the shuttle during these bombardment are expected to charge up and perhaps generate electrical discharges. Although evidence for those kind of discharges have been found from shuttle flights after return from orbit there has not been any direct photographic recording of the discharges. It is suggested that during a high latitude APE mission we should search for those discharges.

3.0 THE APE EXPERIMENT HARDWARE

During the first APE mission in 1985 only a limited set of the APE hardware was flown. As it happened other hardware component parts were included in the flight as part of another experiment the OGLOW experiment. The limited set of APE hardware was named as APE configuration A and the hardware including the OGLOW hardware was called as APE configuration B. This complete hardware configuration is being readied for flight currently.

The APE configuration A consisted of the:

1. Image Intensifier

2. 8 filters
3. Filter changer
4. Filter Pouch
5. Filter Carrier

The APE configuration B hardware is all of the above plus:

1. Spectrometer
2. 135 mm focal length spectrometer lens.
3. Fabry-Perot etalon interferometer.

For the upcoming flight configuration B has been manifested.

The APE 2 hardware was completed as early as December 1987 and was delivered to Johnson Space Center. The instruments were calibrated for intensity and spectral response. This was accomplished with the various filters in imaging mode and also in spectrometer mode. In the spectrometer mode we have also obtained the function of spectral dispersion with linear distance on the image plane. For the absolute intensity calibrations we have used a C14 secondary standard.

3.1 The "Handheld" Imaging Spectrometer

For the investigation of spacecraft glow and related faint atmospheric phenomena we have developed a special spectrometer. This instrument can be used to document alternately the image and the spectra taken from the central portion of the image. This way we can record clearly the position of the spectral slit and identify uniquely the spectrum of different parts of the object.

The instrument has three operating modes. The three modes are schematically illustrated on Figure 6. The top illustration shows the instrument with the grating and slit out of the optical path. In this mode the intensifier camera works in a straight through imaging mode with a real image formed at the pl ne of the slit by the objective lens. A permanent targeting slit is superimposed on the image to provide a fiducial for aiming the system. The image is then collimated by the collimating lens and refocused on the image intensifier photo-cathode by the camera objective lens. The output phosphor of the image intensifier tube is re-imaged on the film or in the viewfinder of the 35mm single lens reflex camera attached to the system. The observer looking through the viewfinder will see the targeting slit super-imposed on the image. In this mode he is able to point the instrument and accurately document the position of the spectral slit on the image.

The second mode shows the spectrometer with the grating in the optical path. In this mode the grating produces an objective spectrum. In addition to the image which was produced in the previous mode another image, the first order image, also appears. The distance between the two images is proportional to the wavelength of the light forming the image.

The third mode represents the high resolution spectrographic mode. In this mode the slit covers are also placed into the optical train. They cover up the image except the narrow slit formed by two parallel bars of the targeting slit. In this mode the system is equivalent to a transmission grating spectrometer with grating rulings of 300 lines per mm. Two identical lenses were used for the first two lenses where both were F/1.4 f=50 mm. The spectrometer objective is a 135mm focal length objective lens. The slit width is of the order of .02 mm.

3.2 APE Hardware Configuration

The three APE hardware configurations are illustrated on Figure 7. The top shows the configuration with filter slider only. This the filtered imaging mode. In the middle configuration the Fabry-Perot is added which is the Fabry-Perot configuration. At the bottom we are showing the spectrometer assembly which is used in the spectrometer configuration. Figure 7 also attempts to illustrate how the various pieces of the apparatus are assembled together.

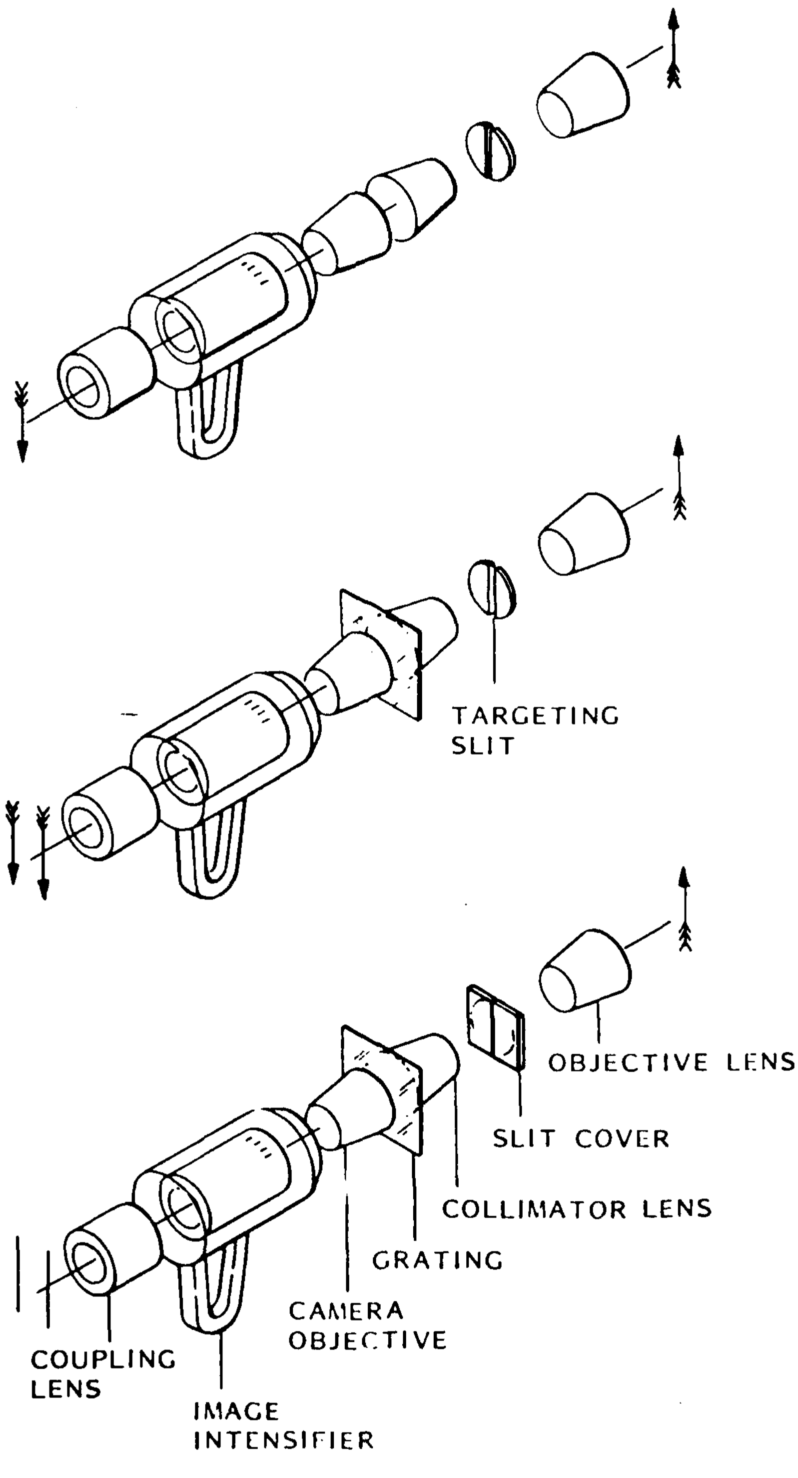


Figure 6. Image intensified slit spectrograph for shuttle glow observations. Top is shown with straight through imaging configuration. middle is shown in objective grating configuration. Bottom is shown in spectrometer configuration.

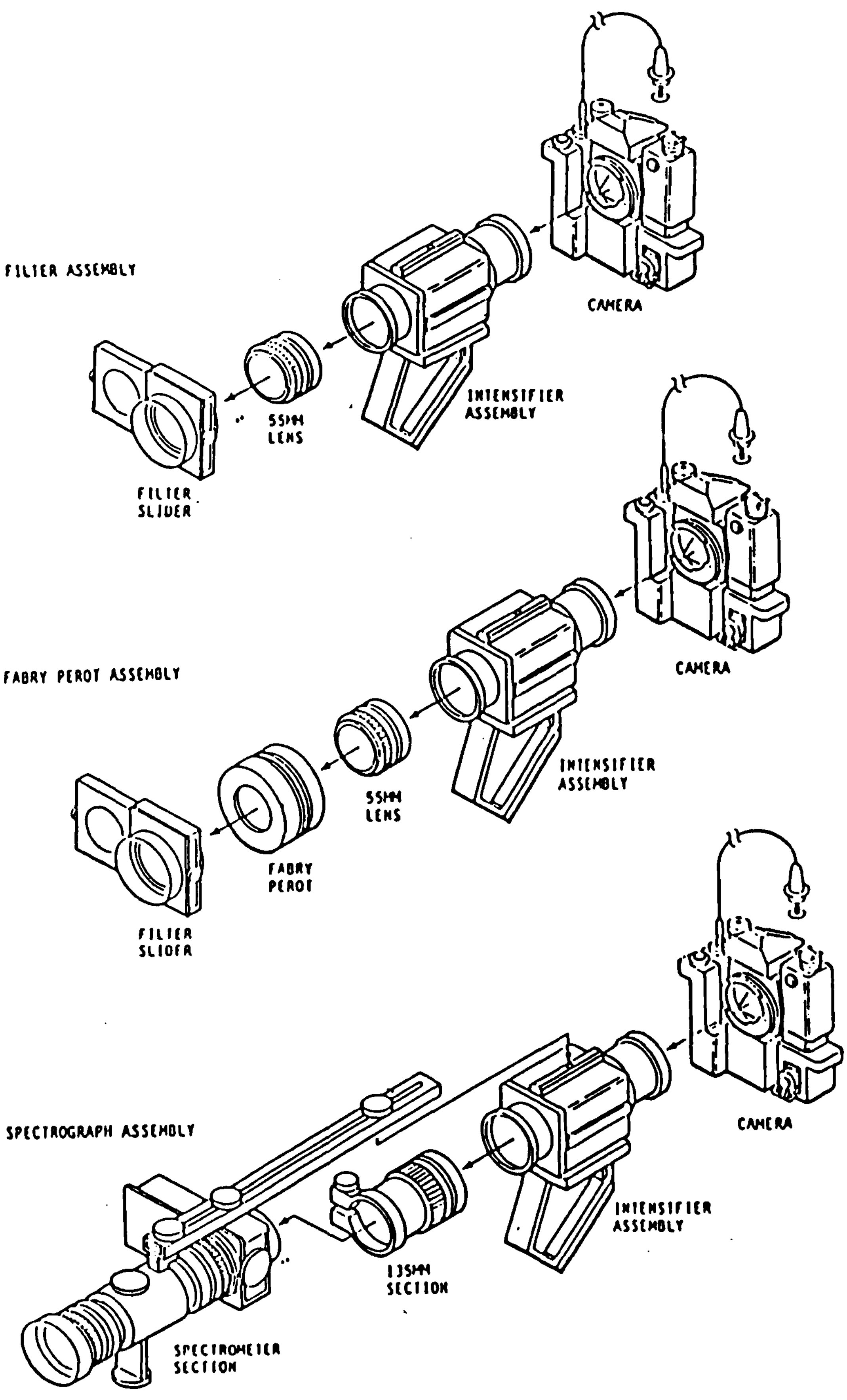


Figure 7. The APE hardware configurations. Top is imaging mode with filter slider; middle is Fabry-Perot configuration; bottom is imaging spectrometer

4.0 FLIGHT OPERATIONS PLANNING

A flight planning meeting was held at Johnson Space Center on the 22nd of March,1989. This meeting was attended by Drs. C. Pike and Edmond Murad from AFGL and Dr. S. B. Mende from Lockheed. The functional objectives were discussed at this meeting and the many operational details were settled.

There are 4 functional objectives associated with the currently base-lined APE experiment:

1. Auroral and Airglow Photography
2. Auroral Effects on the Orbiter
3. Shuttle Glow
4. Thruster induced Effects

4.1 Objective 1: Shuttle Glow

4.1.1 Glow Spectra

Scientific and Technical Objectives.

The main objective is to obtain a good spectrum of the shuttle glow. The only definitive measurement of the shuttle glow in the visible was performed on the 41-D mission in September 1985. The glow spectrometer used had a wavelength resolution of about 30-40 Angstroms. There are only two successful spectral exposures on record. It would be extremely important to repeat the spectral exposures of shuttle glow and take advantage of the improved spectrometer.

Configuration: Spectrograph

Attitude: + or - ZLV and V in + or - Y.

Procedures: The sequence of procedures used to carry out this experiment is:
APE-4, APE-15 and APE-5

View angles: View angles are illustrated on Figure 8.a.

Thrusters should be inhibited for one minute prior to exposure.

4.1.2 Glow Effect On Window

Scientific or Technical objective. To determine the extent to which low light level photography is affected by ram glow. In this experiment we will take an image intensified image of the earth limb and stars in two cases. In one case the window is in the ram and in the other case the window is in the wake.

Configuration: Imaging Mode (White light)

Attitude: No specific attitude is requested. Whichever window is used should be in the wake in one case and in the ram in the other case.

Procedures: APE-2, APE-16, APE-5.

View Angle: View angle is shown on Figure 8.b.

Thrusters should be inhibited for 1 minute prior to exposure.

4.1.3 Glow Time/Temperature Dependence

Scientific or Technical objective. To determine whether glow intensity is changing significantly during the night half orbit. As we enter the nightside on orbit the shuttle surface temperature drops significantly. According to the Swenson et al theory the shuttle glow should become brighter.

Configuration: Imaging Mode Filters.

Attitude: + or - ZLV and v is +Y or -Y.

Procedures: APE-2, APE-9, APE-5.

View Angle: View angle is shown on Figure 8.c.

Thrusters should be inhibited for 1 minute prior to exposure.

4.2 Objective 2. OMS/PRCS/VRCS Photography

Scientific or Technical objective. The spectra of the thruster emissions were never measured during previous missions. There is one early photograph of relatively low spectral resolution which was taken in an objective grating configuration. From this photograph it appears that the thruster emission is also a continuum in the visible and somewhat similar to shuttle glow. The thruster emissions are quite bright and it should be reasonably simple to get a good high resolution spectra from the measurements.

Configuration: Spectrometer. Set the front aperture to F/2.8 Exposure 4 sec.

Attitude: It would be highly desirable to fire in one case into the ram and in the other case into the wake.

Procedures: APE-4, APE-11, APE-5. Jet firing should be synchronized with the exposure. Two crew members are required. One crew member is needed to count down and start exposure sequence while the other operates the thrusters. Upon firing of the thruster, take a series of 3 exposures of the exhaust plume. Repeat the series of 3 exposures for each thruster firing planned during this period of Orbiter darkness.

View Angle: Spectrograph slit to be aligned with centerline of thruster so that spectra is taken of the center of plume from nozzle outward (Figure 8.d).

4.3 Objective 3. Auroral and Airglow Photography

4.3.1 High Latitude Auroral Photography (observations at 50 magnetic or higher)

Scientific or Technical objective. From orbit it is possible to obtain limb altitude profiles. In this experiment we will obtain auroral limb altitude spectral profiles. Such experiments were attempted on 41-G but the improved resolution of the spectrometer should provide a better data set.

Configuration: Spectrometer.

Attitude: The high latitude limb should be in the field of view.

Procedures: APE-4, X, APE-5

View Angle: Set the spectral slit on the limb containing auroras. Slit should be parallel with magnetic field (Close to local vertical in auroral regions) (Figure 8.e).

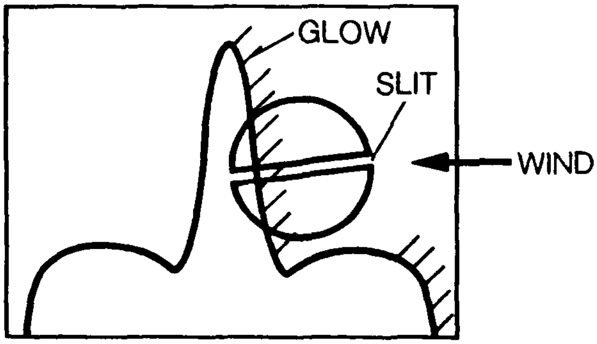


Figure 8.a. Glow spectra

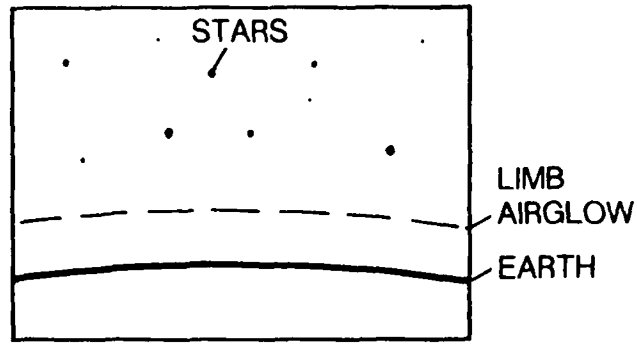


Figure 8.b. Window glow

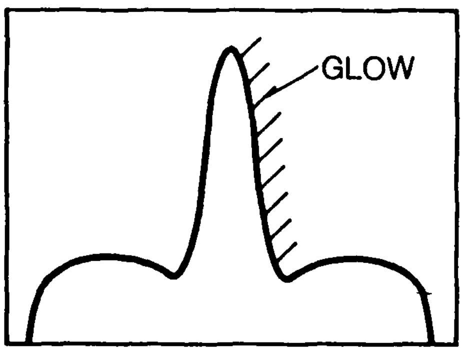


Figure 8.c. Glow image

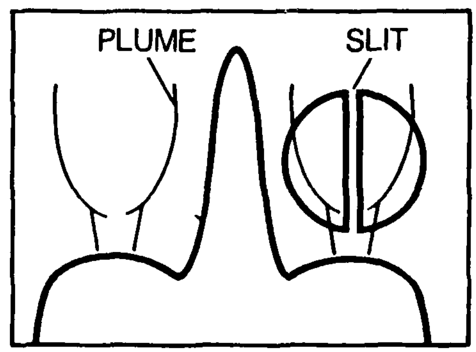


Figure 8.d. Plume spectrum

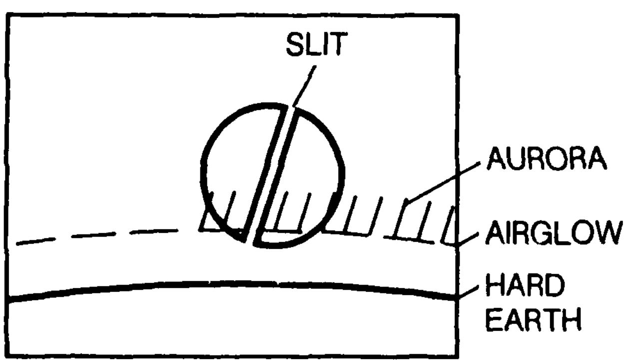


Figure 8.e. Auroral view

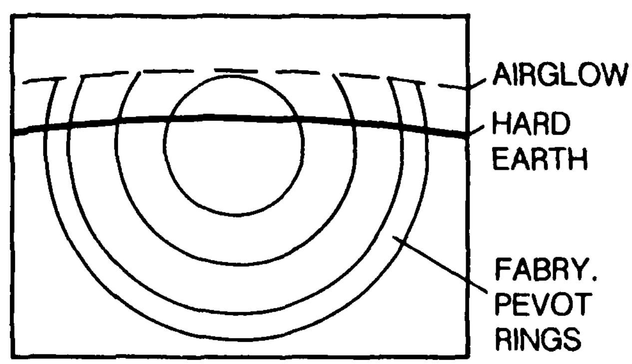


Figure 8.f. Airglow View

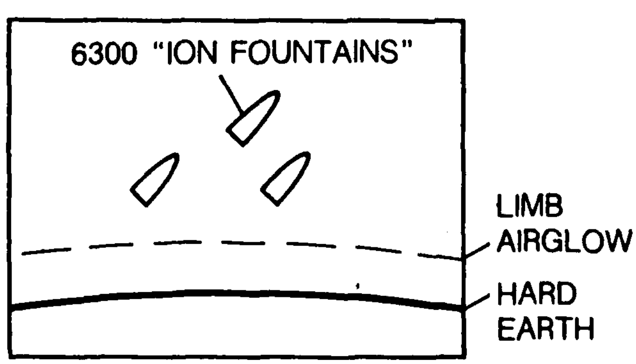


Figure 8.g. Equatorial Airglow photo

Assemble Fabry Perot, (if required) filter carrier, lens hood, and window hood. Point instrument at a limb auroral feature.

4.3.2 Airglow Observations Magnetic Latitude < 50°

Scientific or Technical objective. Airglow limb observations can provide the altitude temperature profiles of the OH and O_2 bands. The dynamics of the atmosphere at 80-100 km is not very well understood. The knowledge of the temperature variations at these altitudes would be of great importance in understanding the dynamics especially gravity waves in the upper atmosphere.

Configuration: Imaging mode including the Fabry-Perot.

Attitude: Image detector must observe the limb (+ or - ZLV O.K.).

Procedures: APE-1, APE-6, APE-5.

View Angle: Take image of the limb with camera centered slightly lower than limb (Figure 8.f).

4.3.3 Airglow Photography Equatorial Magnetic Latitude < 15°

Scientific or Technical objective. Study of airglow enhancements near the magnetic equator. Near the equator there are some special ionospheric turbulence phenomena taking place. 6300 and 7774 airglow shows these effects because their intensity is proportional to the local ion density.

Configuration: Imaging mode with Fabry-Perot.

Attitude: Image detector must observe the limb (+ or - ZLV O.K.).

Procedures: APE-1, APE-7, APE-5.

View Angle: Take image of equatorial limb. Camera should be centered higher than the limb. Need to look at high altitude regions (Figure 8.g).

4.4 Objective 4: Auroral Effects Photography

Scientific or Technical objective. When the orbiter is flying through some local auroral precipitation then the orbiter is bombarded by auroral particles. The purpose of this experiment is to observe if there are any optical emissions caused by the discharges which might occur under auroral bombardment.

Configuration: White light imaging mode.

Attitude: (-ZLV payload bay up).

Procedures: APE-1, APE-Y, APE-5.

View Angle: Take images of the payload bay.

Monitor Thruster History.

CONTRIBUTIONS

Scientists who contributed to the research in this document are:

S. B. Mende, G. R. Swenson, J. H. Doolittle and R. E. Meyerott

PUBLICATIONS AND REPORTS

Two manuscripts which were partially sponsored by the contract were submitted for publication. These are:

Mende, S. B., G. R. Swenson, E. J. Llewellyn, W. F. Denig, D. J. W. Kendall, and T. G. Slanger, Measurements of Rotational Temperature in the Airglow with a Photometric Imaging Etalon Spectrometer. Journal of Geophys. Res., 93, 12861-12870, 1988.

Swenson, G. R. and R. E. Meyerott, Spacecraft Ram Cloud Atom Exchange and N_2 LBH Glow. Geophys. Res. Letters, 15, 245-248, 1988.

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FIGURE CAPTIONS

Figure 1. Schematic representation of the atomic N and O chemistry leading to the formation of NO_2 in an excited state.

Figure 2. Collage of television monitor photographs of the thruster firing as recorded by the orbiter bulkhead closed circuit television cameras. Time counter in seconds and hundredth of seconds. Note that glow on engine pods is enhanced after jet firing.

Figure 3. The function of the thruster glow intensity on the engine pods as a function of time after a thruster firing. The data was taken with the orbiter bulkhead video cameras. Intensity is in arbitary units.

Figure 4. The position of the vernier thrusters on the shuttle orbiter.

Figure 5. The effect of firing thrusters during the exposures. Top left no thrusters fired.

Figure 6. Image intensified slit spectrograph for shuttle glow observations. Top is shown with straight through imaging configuration. middle is shown in objective grating configuration. Bottom is shown in spectrometer configuration.

Figure 7. The APE hardware configurations. Top is imaging mode with filter slider; middle is Fabry-Perot configuration; bottom is imaging spectrometer

Figure 8.a. Glow spectra

Figure 8.b. Window glow

Figure 8.c. Glow image

Figure 8.d. Plume spectrum

Figure 8.e. Auroral view

Figure 8.f. Airglow View

Figure 8.g. Equatorial Airglow photo